PRESIDENT

CLAP,

ON

TERRESTRIAL

COMETS.

CONJECTURES

UPON THE

NATURE AND MOTION

OF

METEORS,

WHICH ARE ABOVE THE

ATMOSPHERE.

By THOMAS CLAP, A. M. LATE PRESIDENT OF YALE-COLLEGE.

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METEORS, &c.

UPON several obfervations made upon fundry Meteors, which have appeared in Europe and New-England, I have collected the following general phænomena :

I. THEY appear like round balls of fire, or globes of red hot iron, or white hot iron, ready to melt, as large as the fun or moon, in the meridian, commonly farrounded with a flame which appears like a tail, with ftreams and fparkles not fo bright as the body. They frequently exceed the light of the moon, and in fome inftances that of the fun, fo as to make a fhadow in the cleareft funfhine.

II. THESE Meteors have been feen paffing through the air, at all points of the compafs, over a fpace of ground above 100, and fometimes above 500 miles long, and above 100 miles wide, with an exceeding great velofity. I could never get obfervations accurate enough, to determine the velocity with any degree of exactnefs. Doctor Halley fuppofes it to be above 300 miles, and Doctor Pringle about 1000, in a minute. I rather fuppofe it does not exceed 500, for the reasons hereafter mentioned.

III. To each particular perfon obferving, who ftands in or near the line of their courfe, they feem to rife while they are coming towards him, and to fall when they are going from him, as the fun rifes and fets, feemingly at a fmall diftance. But by comparing the obfervations made by feveral perfons ftanding a little out of the line of their courfe, at the diftance of 50, 100, or 500 miles from each other, it appears that at their firft approach or appearance they are 50 or 100 miles diftant from the earth ; then they come within 20 or 30 miles of it ; and afterwards are at the diftance of 50 or 100 miles again ; which different diftances feem to arife principally from the curvature of the earth. Or if thefe feveral diftances of any one Meteor have not been accurately determined on both fides of its neareft approach, yet it is evident, that fome Meteors, during the time in which they have been obferved, have been coming nearer to the earth, and others going farther from it.

IV. THESE

IV. These Meteors, in their transit, make a continual whizzing or humming noise; or, as some say, a noise like a great number of drums, or guns, or distant rumbling thunder; which is heard presently after they pass by. And about the time they come nearest the earth, or a little after, the body of the Meteor seems to burst like a bomb, with a great explosion of flames, streams, and sparkles; and presently after there is a very loud noise, sometimes like terrible thunder, so as to shake the ground and houses, like an earthquake, or like the report of a very large cannon near at hand; or, as some say, as loud as a thousand cannon fired together, at 20 or 30 miles distance. And when it is cloudy, noises like distant cannon, or rumbling thunder, have been heard passing through the air, without any distinct light.

V. Although these Meteors, by reason of their extreme velocity and great distance, generally become invisible in about a minute after they pass by; and as they recede from any person, presently make but a small angle with the horizon, and seem to be suddenly intercepted by horizontal clouds, houses, &c. yet there is no sufficient evidence that any of these high Meteors, which have moved 100 miles or more, ever did really fall to the ground, or become wholly extinct; though after the emission of so much of their fire in the explosion, they are not so bright, and have no flame or tails.

VI. These Meteors generally appear as often or oftener than once in 20 or 30 years. Near ten of them have been seen in England within these 100 years; as related in the Philof. Transf. Abr. vol. II. page 200; vol. IV. by Jones, part II. page 134, 135, 136, 137, 156; vol. VIII. page 121, 123; with that in 1758, ingeniously treated upon by Doctor Pringle. Three or four such Meteors have been observed in New England within these 50 years; but as they have been generally supposed to be of the same nature with thunder, lightning, shooting stars, and such like lower Meteors, which seem to have no existence above two or three minutes, there have not been such critical observations made upon them as I could wish may be made hereafter. Yet these general phænomena, I take to be as certain as can ordinarily be collected from such sudden, transient, and unexpected observations, generally made by the lower sort of people: And have therefore been led to conjecture a new Theory of the nature and motion of these high Meteors.

Now to assign a natural cause or reason for any thing, is to resolve it into the general laws of nature, by which the wise Creator governs the world; and to shew its connection with other things, according to those general laws by which we find the universe is governed, so far as we are acquainted with it. And the fewer laws we have recourse to, which will solve all the apparent phænomena, the greater is the probability that we have hit upon the true theory. And,

I. If the apparent diameter of these fiery globes is equal to those of the sun or moon, in the meridian, and subtends an angle of above half a degree, at the distance of 50 miles from the observer, then it is evident that their real diameter is half a mile at least.

II. It seems evident that these globes are solid and firm, at least as to the external parts.

1. Because, they preserve their globular shape and motion throughout their whole course, and after the explosion. For if they consisted only of inflammable

matter,

matter, of the nature of pulvis fulminans, or a train of gun-powder, fired at one end, (as some of the lower Meteors seem to do) there would be no probability that they would invariably preserve their exact globular shape; but would melt down, burn up, or dissipate with such an intense heat, as must cause or accompany such a vast explosion of flame and sound.

2. BECAUSE, they are strong and firm enough to withstand the force of so great a shock as is given at the explosion. The noise is generally represented as being equal to loud thunder, a large cannon near by, or a thousand cannon at the distance of 20 or 30 miles. And I suppose that a thousand cannon fired at the distance of 25 miles, give just as loud a report as one cannon at the distance of a quarter of a mile. The greatness of the explosion being in a sesquiplicate ratio of the distance heard *. And if the Meteor is about 30 miles high, where the atmosphere is 500 times more rare than it is upon the earth, in order to produce the same sound to our ears, it must be equal to 500,000 cannon fired upon the earth. And if this explosion is made by an elastick fluid, as violent as gun-powder, then the matter of this globe must be as strong and firm as the iron of cannon, and the sides of the same proportional thickness, which is about 50 rods, in order to stand such a violent shock. If this explosion is caused by an elastick fluid, of the nature of electrical fire, as I shall afterwards shew, then the firmness of the globe must be almost the same. For when a body is charged with it, at or near the instant when it is discharged, the fire is retained in it with as great a force, as that with which it is discharged, or would strike against another body. So that the force with which the fire goes out, by any elastick spring, or repulsive power, is impressed on the body it leaves. Or if it be drawn out by the attraction of some other body, the force of that attraction is taken off from the body it leaves, which will have the same effects upon it. And hence a large phial or jarr, when it is overcharged with electrical fire, will sometimes burst, like a bomb, and that although it was strong enough to withstand the weight or expansion of the air, which is 15lb. on every superficial inch; and such a pressure upon a sphere half a mile in diameter, will lie above 5,000,000lb.

IF it should be objected, the clouds are not solid bodies, and yet they emit a violent explosion;—to this I reply, that the explosion of thunder and lightning is but very small, in comparison with that of a Meteor; for, thunder is rarely heard 10 miles, whereas, a Meteor may be heard above 100; and the thunder must be within half a mile, to be heard as loud as a Meteor at the distance of 30. And upon computation of the different distances and rarity of the air, it will appear, that the explosion

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* The undulations of sound are propagated from a sonorific body in concave shells, increasing very much like the blowing up of a bladder. The whole pressure of the air upon the inside of the shell, is equal at all magnitudes, taking the whole shell together; but lesser upon each particular part or spot, as it grows bigger. The magnitude of the sound is in proportion to the solid content of the spherical shell; and the audibility of it (at any particular distance) is in proportion to the pressure upon any particular part, at that distance. Therefore, as the solid content of the sphere is to the superficies, or as the cube of any number is to the square of the same number, so is the magnitude of a sound to the distance heard. Or multiply the distance by the square root of itself, and it gives the magnitude of the sound.

Cube.	1	8	27	64	125	216	343	512	729	1000 Magnitude.
Square.	1	4	9	16	25	36	49	64	81	100 Distance.
Root.	1	2	3	4	5	6	7	8	9	10

Thus

explosion of thunder is not a 10,000th part so great as that of a superior Meteor; and yet a cloud, containing 5,000,000 tuns of water, when it discharges its electrical fire, recoils as much as a cannon, in proportion to its weight, and is so violently agitated, that the small bubbles are suddenly dashed together into drops, which immediately fall down in rain. And if the explosion of a Meteor is so great, when the noise heard is only equal to the report of a single cannon near by; how great must it be in those instances, where it causes an earthquake 40 or 50 miles round? It seems impossible that there should be such a prodigious forcible explosion, without making an alteration in its perfect globular shape, unless it be very rigid and firm*.

3. Their solidity appears from their extreme velocity for many hundreds of miles: For, if a meer flame, smoke, or powder, or any thing not strongly cemented together, was shot out of a cannon at the velocity of 500 miles a minute, it would immediately dissipate or dissolve: Or, if so great a body should continue together, it would necessarily drive before it a large column of air, which, by the resistance of the *vis inertiæ*, would be extremely condensed, and the friction of it, by the sides of the Meteor, would presently wear it away, unless it was very hard and firm. The round ball always runs away, and leaves the flame, tail and sparkles behind it; just as a cannon ball leaves the fire and smoke, or the nucleus of a comet runs before its tail. Upon these considerations, it seems evident, that the globe of these Meteors is a firm, solid substance; at least, as to the external part.——I would, then, observe,

III. There is a continued whizzing, humming, or rumbling noise, like distant drums, guns, or thunder, made by these Meteors, and heard presently after they pass by, about a quarter so loud as the explosion: I suppose this is caused by the friction of the Meteor upon the atmosphere;—for a cannon ball, of six inches in diameter, passing through the air, with 1-25th part of the velocity of the Meteor, will make a humming noise, which is generally heard two miles. Now, if we multiply the square of the difference of the velocities, into the square of the difference of the diameters, we shall find that the resistance of the air upon the Meteor is, to that upon a cannon ball, as 17,000,000,000 to 1.† And 6,700,000 being the square of that number of which 17,000,000,000 is the cube, will represent the proportion of the distance in which the humming of the Meteor will be heard farther than that of a cannon ball: And being diminished to a 500th part on account of the rarity of the atmosphere, the proportion will be as 13,400 to 1. And because the humming of the

Thus in the explosion of gun-powder: supposing 31 cubic inches to a pound.

Quantity.	Cubic inches, 1	310 : 10*lb.*	620 : 20*lb.*	930 : 30*lb.*	1240 : 40*lb.*
Distance.	Miles, - 1 1-2	68	109	141	173

So the sound of a bell according to its weight.

Quantity.	1*oz.*	16 : 1*lb.*	100*lb.*	500*lb.*	1000*lb.*
Distance.	5 *rods.*	30	640 : 2 *miles.*	1890 : 6	3000 : 9

Mountains, contrary or confused winds, and such accidental causes, may sometimes interrupt the sound, so as not always to be heard exactly in this proportion.

* *Since these balls of fire have been observed to accompany earthquakes, I would propose it, to be considered, whether the explosion of Meteors may not oftentimes be the cause of earthquakes, as well as the eruption of subterraneous fires.*

† *See Newton's Princip. Math. Book II. Prop. 35. Cor. 5.*

the cannon-ball is heard but a 50th part so far as the report of a cannon, that number must be divided by 50, which will make the humming-noise of the Meteor equal to the report of 268 cannon, at the distance of 25 miles. And the explosion of the Meteor being represented to be equal to 100 cannon at that distance, the humming-noise will be 1 4th part of it. And this humming noise will be less, as the distance or altitude of the Meteor is greater.

IV. The great explosion and flame attending these Meteors, is caused by the discharge of electrical fire, collected by the friction of the atmosphere, and emitted about the time, or a little after, it approaches nearest to the earth, and becomes overcharged I suppose electrical fire is not essentially different from common fire, and is a kind of universal element diffused, in some degree, into almost all bodies in the universe, and, by friction, may be collected into a much greater quantity in some particular bodies. And, when the whole suddenly rushes out in one place or stream, it is there so greatly collected or condensed, like the rays of the sun in a focus, that it becomes common fire, capable of inflaming any combustible matter ; and, by the extreme celerity of its motion, so violently agitates the air, as that its elastick spring becomes sensible to the ear. Common experience teaches, that when a collection of visible fire is once begun, the friction of the air upon it, at the velocity of half a mile a minute (as in the blowing of a pair of bellows) will inflame and increase it to a very great degree : And, therefore, it is reasonable to suppose, that the friction of the air, at the velocity of 1000 half miles in a minute, (the force of which is 1,000,000 to 1) will collect fire where it was not begun before, or but in a low degree ; as all bodies grow warm by friction : And, we find by experience, that fire is often collected by soft bodies, which do not make so great a resistance as condensed air, though moved with a velocity much less than that of a Meteor. Dr. Boerhave, on Chymistry, page 249, speaking of collecting fire by friction, says, " The " surfaces of two bodies being applied together, one may pass so swiftly by the other, " as that nothing but fire, the swiftest body in nature, can succeed immediately into " the vacant places ; and by that means it becomes collected, in the path of the " moving body, and so it has, as it were, a fiery atmosphere around it. And, " (page 231) that balls exploded in the night, out of great guns, grow hot in their " passage through the air, so as sometimes to appear ignited." And if a cannon-ball will collect some visible degree of electrical fire, then the Meteor, which has above twenty-five times the velocity, and consequently above six hundred times the friction, may collect such a quantity of electrical fire, as may be sufficient to answer all the phænomena. For a soft piece of leather moving upon an electrical globe or tube, with the velocity of two and an half feet per second, or 150 feet, which is a thirty-fifth part of a mile, in a minute, will collect a large quantity of electrical fire in a very short time. And I suppose 150 superficial inches of leather, passing over an electrical globe or tube, with the velocity of 150 feet a minute, and each inch passed with a force equal to the weight of one pound, will be sufficient to raise a large spark or snap of electrical fire ; especially after the globe is once sufficiently warmed. The motion of the leather being at the rate of a thirty-fifth part of a mile a minute, and that of the Meteor 500 miles, the proportion of their velocities is as 1 to 17,500 ; and the momentum or effect produced will be just the same, whether we take the number of pounds weight in the air (pressing upon the globe) at the velocity of the Meteor, or else 17,500 times so many pounds at the velocity of the leather.

A globe passing very swiftly through the air, drives before it a column of air almost equal to itself. The elastick force of the air will not be sufficient to overcome

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its vis inertiæ, so as suddenly to protrude the air much before it, or on either side. By the motion of sound, we see that the elastick spring of the air will not move it more than 12 miles in a minute, which being not a fortieth part of the velocity of a Meteor, is very inconsiderable in this case. And as action and reaction are always equal, the vis inertiæ of the air, and the velocity communicated to it, by its resistance against the Meteor, makes the same action upon the Meteor as it would do if the air was non elastick*. The Meteor in two minutes moves through a cylinder of air 1000 miles long and half a mile in diameter; which being taken one place with another, 500 times rarer than common air, is equal in weight to two miles of common air or 12 feet of water; which, upon computation of 76lb. for every cubic foot, is 5,000,000,000lb. As the Meteor moves 17,500 times faster than the leather on the tube, multiply the number of pounds by that sum, and the product will be 87,500,000,000,000, equal to the number of pounds, moving with the velocity of the leather, which being divided by 150lb. (which make one electrical snap) the quotient will be 583,000,000,000, the number of electrical snaps collected.

AND that the Meteor will contain such a quantity, is evident, because a phial holding a pint charged with electrical fire, will give a snap which can be heard 50 feet, or 100th part of a mile. A cannon is heard 100 miles, which is 10,000 times so far as the phial; which being multiplied by the square root of itself, gives the quantity of the explosive force, or sound, which is heard so far. Then 10,000×100 = 1,000,000, the number of electrical snaps which are equal to the report of a cannon, and consequently 500,000,000,000 snaps are equal to 500,000 cannon. Now the Meteor being a sphere half a mile in diameter, contains 574,000,000,000 pints, which will give the number of snaps before-mentioned equal to 500,000 cannon; besides a seventh part overplus which may remain in the Meteor.

AND to shew that 1,000,000 electrical snaps are equal to the report of a cannon: I suppose that a quantity of powder equal to a cube of near 1-10th part of an inch, on each side, being fired out of a proper instrument, will make a report which may be heard 50 feet, like an electrical snap; and 1,000,000 such quantities, which is about 20lb. being fired out of a cannon, will be heard 100 miles.

As all these proportions agree among themselves, it is probable they may be near the truth; but if they are not, they will equally serve to lead the mind into a conception, how it is possible that such a vast solid body may be so charged with electrical fire, as to give an explosion equal to the report of a cannon near by, or to 1000 cannon at the distance of 30 miles.

V. THIS mighty body, which if it be near as solid as iron, must weigh about 2,000,000,000 tons, cannot be raised up, near 100 miles from the earth, by any laws of nature that we are acquainted with. Water, when rarified into the finest mists or bubbles, cannot be carried up above 3 or 4 miles by the weight of the atmosphere; and when it is condensed to about an 800th part of the weight in its natural state, it immediately falls down again. Much less can it be carried up 40 miles where the air is near 3000 times as light. And it seems absolutely impossible, that it should be carried up 100 miles, which is double the utmost extent of the atmosphere, Or if we could suppose it possible, that any kind of matter could be rarified so as to be carried up so high, yet when it comes to be consolidated, a thousandth part so much as these Meteors, it must fall directly down.

VI. It

* Newt. Prin. B. II. Prop. 33. Cor. 3.

VI. It is beyond the power of any laws of nature, already known, to give such a heavy body such a prodigious projectile velocity, above 20 times so great as that of a cannon ball; and by multiplying the difference of their weights into the difference of their velocities, it appears that the momentum or force impress'd must be above 3,000,000,000,000 so great. All other bodies moving in the universe, that we know of, were at first set in motion by the immediate hand of the omnipotent Creator; and are since continued in motion according to the simple laws of projectile and centripetal force. And as our surest reasoning in these things is by way of analogy, according to the known laws of nature, we must conclude that these Meteors are governed by the same general laws; and as all the cœlestial bodies, are so remote that they can have no sensible influence upon them, when they are within 100 miles of the earth, it is evident that the earth must be the attractive central body, round which they revolve; as the secondary planets revolve round the primary, or rather as comets revolve round the sun in long elipses, near to a parabola.

VII. I shall therefore calculate the motion of these Terrestrial Comets round the earth, on the same principles as Doctor Halley calculates the motion of comets round the sun.

1. A body revolving in a circle, at the distance of 4000 miles from the centre, which is about 25 from the surface, will perform its revolution in 84 minutes. For as the cube of the moon's distance is to the square of its periodical revolution in minutes, so is the cube of 4000 to the square of 84', which is 300 miles in a minute: But if it revolves in an elipses, near to a parabola, its velocity is augmented as 7 to 10, nearly, and will be 428 miles in a minute: The annual and diurnal motion of the earth may make a small difference.

2. As the area of a circle 0,785 is to 84 minutes, so is 1-3d to 35', the time in which it will describe a quadrant of a parabola, with the velocity of a circle.

3. As the square root of 2 is to 1, so is 35 minutes, the time as in a circle, to 25', the time as in a parabola. Therefore, the Meteor describes a quadrant, or 100° of mean motion, in 25', which is 4 degrees of mean motion, and 6° 6' angular motion from the perihelion, in one minute. Upon these data I have calculated the following table of the motions of this Terrestrial Comet. The first column contains the minutes of time before and after the perihelion or perigee: The second, the degrees of mean motion: The third, the degrees of angular motion: The fourth, its distance from the centre of the earth: And the fifth, its distance from the surface of the earth, supposing its least distance, at the perigee, is 25 miles: The sixth, its motion from the perigee, in its orbits, in miles.

Time.	Mean motion.	Ang. motion	Dist. from cent	Dist. fr surf.	Dist. in orbit.
0 ...	0°	0° 0'	4,000	25	0
1	4	6 6	4,011	36	428
2	8	12 8	4,045	70	854
3	12	18 2	4,101	126	1,280
4	16	23 45	4,177	202	1,700
25	100	90 0	8,000	4,025	
1h. or 60	240	118	15,076		
24h.	5760	160 58	146,200		

To a person who stands at the perigee, at the distance of 428 miles, it will appear almost in the horizon.

This calculation seems to answer exactly to all the apparent motions of these Terrestrial Comets, and particularly that they appear first to be 50 or 100 miles distant from the earth, then, in their course, to come within 20 or 30 miles of it, and afterwards are at a greater distance again; as may be clearly seen in the delineation annexed: It also seems to determine its real velocity with a greater precision than the most critical observations hitherto made: For, if it moves less than 300 miles in a minute, it must, in a little time, fall to the earth; and if it moves more than 428, it must go off in an hyperbola.

The preceding calculation is founded upon the known laws of motion, in which we cannot be mistaken; but we have room for different conjectures about the number and periodical revolutions of these Terrestrial Comets; yet we are circumscribed within certain limits. On the one hand we must not suppose that their number is so great, or that their periodical revolutions are so frequent, as to exceed observation: On the other hand we must not suppose that their periodical revolutions, and transverse diameters, are so great, as that, in their apogee, they would be in danger of being carried away, or greatly disturbed in their motion, by the attraction of Venus, or any other cœlestial body. It seems most natural to suppose, that there are more than one, and that their orbits are very differently situated, like those of the solar Comets, in order to account for their different motions to all parts of the Heavens: Though, if we should suppose that there is but one only, it seems possible that all these various motions might be accounted for, by the diurnal and annual motion of the earth, and the constant attraction of the moon, in its various longitudes and latitudes, upon the Meteor, in the several parts of its orbit; which must constantly change the situation of it, and may possibly, in length of time, carry its inclination, apogee and nodes, to every part of the Heavens. By the observations which have been made, it seems evident, that one has been seen in each country, oftener than once in 30 years. Upon the surface of the terrestrial globe, there are 1000 countries, each about 500 miles square; so that 30 of them may appear somewhere in the world within the compass of a year, and yet not be seen in each particular country so often as once in 30 years. Let us, then, conjecture for the present, until we have farther light by more accurate observations, that there are 3 such Comets revolving round the earth, whose mean distances are about as great as the moon's, and, therefore, performing about 36 revolutions in a year; then one of them will appear in each country of 500 miles square, once in 27 years: And so often, at least, they have been in fact seen in Old England and New. This conjecture, I think, will fully solve all the various phænomena of these Meteors which have hitherto been observed. And if their periodical revolutions are once in a month, they will lose but little of their heat in their apogee, and so will be prepared to receive and emit a large quantity of fire when they come near the earth: Indeed, by their friction upon the atmosphere, they will lose near an hundredth part of their velocity, and so, in length of time, will be in danger of falling to the earth, sooner than the planets are of falling to the sun. But this may, in some measure, be prevented, by the greater density and pressure on the lower side---the explosion towards the earth may cause it a little to recoil from it;---and a wise Providence may so order the situation of their orbits, as that once and a while the attraction of the moon, or some other heavenly body, may accelerate their motion and enlarge their orbits. As Mr. Whiston supposes, the Comet, at the flood, accelerated the motion of the earth, and made its annual revolution 5 days and a quarter longer than it was before.
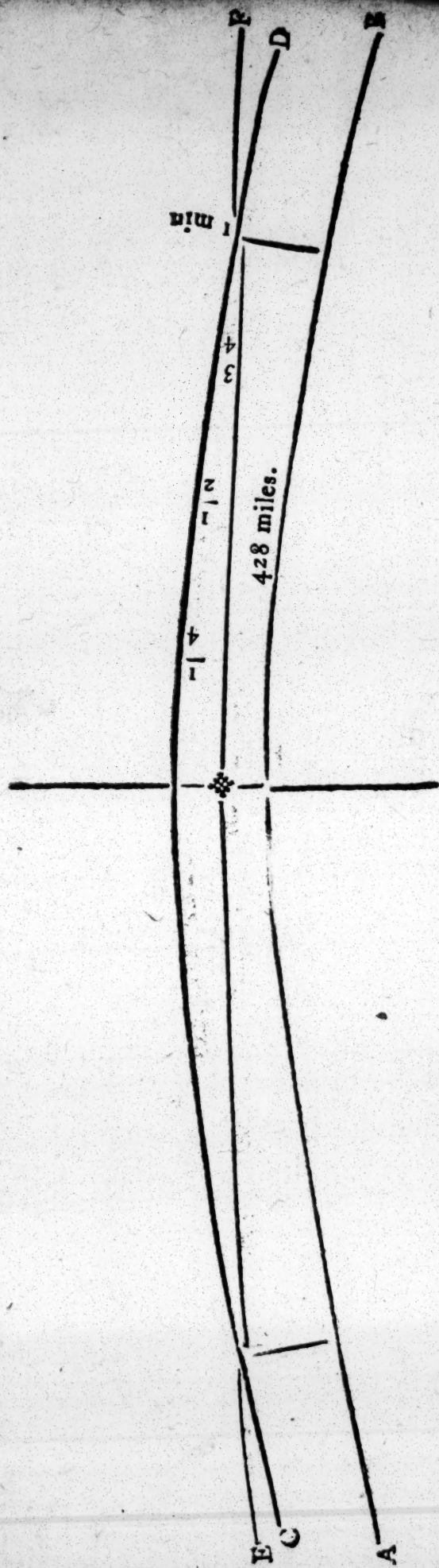
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Our observations have heretofore been so imperfect, as that we cannot easily determine minute circumstances; but the general theory seems highly probable, not certain, that these superior Meteors are solid bodies, half a mile in diameter, revolving round the earth in long elipses, their least distance being about 20 or 30 miles; that, by their friction upon the atmosphere, they make a constant rumbling noise, and collect electrial fire; and, when they come nearest to the earth, or a little after, being then overcharged, they make an explosion as loud as a large cannon.

I shall add one conjecture respecting the use and benefit of these Meteors.——It is possible that, by their violent explosion and agitation, they may cleanse and purify the air, and render it more salubrious to mankind : much more than thunder and lightning. There is an observation in the Phil. Tranf. Abr. Vol. VIII, page 519, which seems much to favour this conjecture; it is in these words : " A Meteor was " seen over England and Ireland, and at Venice, at the same time : It appeared " like a great ball of fire, which burst with an explosion which shook great part of " the Island, and seemed to set the whole atmosphere on fire. This Meteor put an " end to the Catarrh and Diarrhea, and restored a general health."

The line A B, represents part of the earth's circumference.
The line C D, represents the top of the atmosphere.
The line E F, represents part of the orbit of the Meteor.
The figures 1 2 3. represent the distance of the Meteor, in minutes of time, from the perigee.
S C A L E, 200 miles to an inch.

If the least distance of the Meteor from the earth, at the perigee, be 20 miles; then its distance from the perigee and from the earth in the several minutes and parts of a minute of time, from the perigee, will be as follows :

Minutes & parts of a min.	0	1-4	1-2	3-4	1	1-4	1-2	3-4	2	1-4	1-2	3-4	3	1-4	1-2	3-4	4
Distance from perigee.	0	107	214	321	428	535	642	748	854	960	1067	1174	1280	1385	1490	1595	1700
Distance from earth.	20	20,7	22,8	26,4	31,4	37,8	45,5	54,6	65,2	77,1	92,2	104,8	120,7	138,1	156,8	175,9	196,8